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**FINAL REPORT TO THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
PARTICIPATION IN THE
INFRARED SPACE OBSERVATORY (ISO) MISSION
UNIVERSITY OF HAWAII BLOCK GRANT**

NAG 5-3370

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**Period of Award:
17 May 1996 – 14 August 2001**

1) THE ISO CENTRAL PROGRAMME NORMAL GALAXY SURVEY

BACKGROUND

Robert D. Joseph
Principal Investigator

Joseph is an ISO Co-Investigator. The "ISO Normal Galaxy Survey" is a Guaranteed Time project in the ISO Central Programme developed by the ISO Co-Investigators. This is a complete and unbiased survey of an optically selected, magnitude-limited sample of 77 spiral galaxies. The ISO measurements include imaging at $\sim 12\mu\text{m}$ using ISOCAM, and photometric imaging using ISOPHOT at $\sim 60\mu\text{m}$, $\sim 100\mu\text{m}$, and $\sim 180\mu\text{m}$. This program was awarded about 27 hours of ISO observing time. It includes 13 collaborators located in the U.S.A., Scotland, England, France, Germany, Spain, and the Netherlands.

Joseph and George Bendo, the graduate student working on this project, have also obtained complementary J, H, & K imaging using ground-based telescopes for all the galaxies in the sample. These data are essential to interpret the ISO data. Additional ground-based observations we have obtained to extend the scientific application of the ISO database include sub-millimeter photometry ($450\mu\text{m}$ and $850\mu\text{m}$) and 1 - $2.5\mu\text{m}$ near-infrared spectroscopy. We have also used databases for optical imaging, radio 21 cm HI measurements, and x-ray imaging from the Chandra satellite. We expect this material to become a major research resource on spiral galaxies for the next decade.

PROGRESS

All the ISO data have been transmitted from the ISO Data Centre, reduced, and calibrated. This has been rather labor-intensive as new calibrations for both the ISOPHOT and ISOCAM data have been released and the algorithms for data reduction have improved. We actually discovered errors in the calibration in earlier versions of the software. However the data reduction improvements have now converged and we have a self-consistent, well-calibrated database.

It has also been a major effort to obtain the ground-based JHK imaging, $450\mu\text{m}$ and $850\mu\text{m}$ imaging and the 1- $2.5\mu\text{m}$ near-infrared spectroscopy for most of the sample galaxies. However this is all complete and we are in the final interpretation and publication stage for this project.

The major 47-page paper which makes the ISO data available to the broad scientific community, "An ISO Atlas of Spiral Galaxies," has been accepted for publication in the *Astronomical Journal*. Two additional papers are in draft form and two more are in preparation. The tentative titles of these papers illustrate the scientific application of these data: "Star Formation Along the Hubble Sequence in the ISO Atlas of Spiral Galaxies," "Far-Infrared Dust Temperatures in the ISO Atlas of Spiral Galaxies," "Starburst Activity and Stellar Populations in the ISO Atlas of Spiral Galaxies," and "X-Ray Properties of Spiral Galaxies in the ISO Atlas of Spiral Galaxies." Several additional studies using these data are also forseen.

2) JOINT U.S.--JAPAN OBSERVATIONS WITH THE INFRARED SPACE OBSERVATORY: DEEP SURVEYS AND OBSERVATIONS OF HIGH-Z OBJECTS}

David B. Sanders
Principal Investigator

All of the ISO data (~71 hours) were successfully obtained and delivered to the Japan and U.S. investigators.

ISOCAM data. A 13 hour integration (taken over 4 contiguous orbits) was obtained in the LW2 filter for a 3×3 arcmin² region centered on the position of minimum HI column density in the "Lockman Hole." The data were obtained in microscanning mode. This integration is about 2.5 times deeper than that obtained by the European consortium for the Hubble Deep Field. An additional 18 hours of integration were obtained in the LW2 filter of 3×3 arcmin² region centered on the Hawaii SSA13 deep field. This is the deepest integration obtained in the LW2 filter by ISOCAM.

ISOPHOT data. Approximately 40 hours of data were obtained in the C90 and C160 filters, covering a 40×40 arcmin² region in the "Lockman Hole."

Reduction of the LW2 integration of the SSA13 Deep Field was carried out and the data were compared with existing optical and near-infrared ground-based images of the SSA13 field in order to identify possible counterparts of the 7-micron sources detected by ISO. Reduction of the C90 and C160 data was successfully carried out and the data were also compared with optical and radio maps of the region in order to identify counterparts to the far-infrared sources.

In summary, the ISOCAM and ISOPHOT data obtained exceeded expectations in both the quality of the reduced data and in the overall S/N achieved in the final co-added maps. These data represent approximately a factor of 7-10 improvement in S/N over the IRAS all-sky faint source survey. The ISO deep field data have allowed us to detect luminous far-infrared sources out to redshifts of ~ 1.5 , and to verify the steep evolution in the luminosity function of luminous infrared galaxies over the redshift range $z = 0 - 1$ that was seen at the faintest flux levels obtained in the limited amount of IRAS ultra-deep field data. To date, sixteen papers have been published (or are in press) summarizing the scientific results of our ISO deep fields program. They are listed below.

3) CORRELATIONS BETWEEN FAR-INFRARED SPECTRA AND QSO HOST GALAXY MORPHOLOGY

Alan Stockton
Principal Investigator

Using IRAS data, we identified an intriguing possible correlation between QSO host galaxy morphology and far-infrared spectral energy distribution. The objective of the ISO program was to explore this correlation for a sample of QSOs at higher redshifts than the IRAS QSO sample. The ISOCAM 12-micron images obtained gave satisfactory

fluxes for 5 of the 7 objects observed, but none of the objects were detected in ISOPHOT 60, 100, or 160 micron observations. The upper limits on the fluxes do not usefully constrain the spectral-energy distributions, so no conclusion on the main point of the program is possible. However, the 12-micron imaging and the ground-based imaging obtained in support of this program may be useful in related research programs.

4) EXTREMELY RED GALAXIES AND SEARCH FOR PRIMEVAL GALAXIES AROUND $Z = 3 - 4$ QUASARS

Esther Hu
Principal Investigator

The program was to investigate highly reddened, potentially primeval galaxies in high redshift ($z \sim 4$) quasar fields. However, ISOCAM and ISOPHOT observations only provided upper limits on the spectral energy distributions at $7 \mu\text{m}$ and $175 \mu\text{m}$ for one of the two brightest, ultra-red objects in this field. The second object, HR10, was found to have $7 \mu\text{m}$ fluxes which, when combined with HST red and near-IR observations and ground-based submillimeter observations (e.g., Dey et al. 1999, *ApJ* 519, 610; Cimatti et al. 1998, *Nature* 392, 895), reveal it to be a dusty ultra-luminous galaxy of the Arp 220 type at a redshift $z = 1.44$. ISOPHOT sensitivities provide upper limits consistent with this interpretation, but do not provide detections.

PUBLICATIONS (in reverse chronological order)

A Deep 6.7 Micron Survey in the SSA13 Field with ISO, Y. Sato, L. L. Cowie, Y. Taniguchi, D. B. Sanders, K. Kawara, H. Okuda, K. Wakamatsu, T. Matsumoto, R. D. Joseph, Y. Sofue, H. Matsuhara, *Astron. Ap.*, in press, (2002).

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UNIVERSITY OF HAWAII AT MĀNOA

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February 12, 2002

Dr. Ronald J. Oliverson
NASA Goddard Space Flight Center
Mailstop 681.0
Greenbelt, MD 20771

SUBJECT: Final Technical Report, NAG 5-3370

Dear Ronald Oliverson,

Enclosed is the final technical report for the above referenced contract entitled, "Participation in the Infrared Space Observatory (ISO) Mission" under the direction of Drs. Robert D. Joseph, Principal Investigator, David B. Sanders, Alan N. Stockton, and Esther M. Hu, Co-Investigators.

Please contact me if you have any questions.

Sincerely,



Chris Kaukali

Enclosure

CF:
Adrian Jefferson, Code 210.G
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